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NEW TECHNOLOGY RESEARCH: COSTS AND BENEFITS

Linda R. Cohen
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FINAL REPORT

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Notice

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16. Abstract

The objective of this research has been to develop a methodology by which Caltrans may evaluate research and develop a portfolio of proposals for consideration. Increasing productivity is emphasized as the priority goal because research should be appraised in terms of its contribution to economic efficiency.

Research is the driving force behind this state's, and our nation's, productivity. It is through research that public agencies and firms acquire the knowledge that enables them to utilize capital investment efficiently. California must continue to fund research in order to ensure development of new products and improved management. Only through such investment will California regain its preeminence in the nation's economy.

Every proposal must be evaluated to determine if the research will make a positive contribution to economic growth. Cost-benefit analysis (CBA) is a technique which examines the merits of competing proposals. The Net Present Value (NPV) method for CBA is recommended. Only proposals with a positive NPV should be funded, and given limited resources, proposals with a greater NPV should receive a higher priority.

Forecasting techniques are required to estimate the magnitude of future benefits in transportation. Techniques used should include the value of time saved and if possible, value of safety and environmental benefits. Case studies on highway, transit, and rail systems are utilized to illustrate the methodology.

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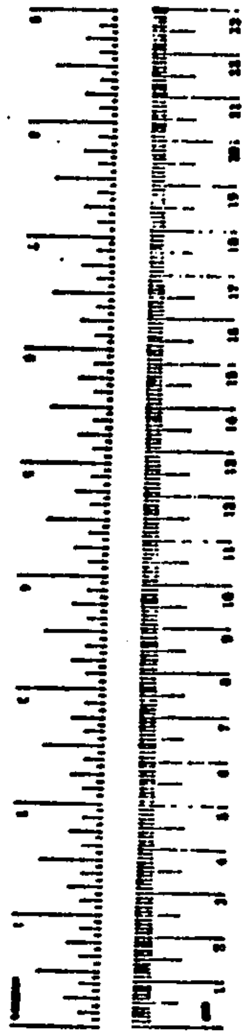
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

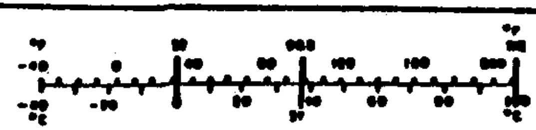
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENTS

Procedures for the evaluation of transportation projects are well established, and we have benefitted from the critical review provided by David Lewis, Primer on Transportation, Productivity and Economic Development, Washington, D.C.: Transportation Research Board, 1991. By contrast, little guidance was available on methods to evaluate transportation research proposals. We have adapted cost-benefit analysis for this purpose and made recommendations on how it might be extended and improved.

In keeping with purposes of university research and training, we have required a high degree of student involvement in the research. Karen Griffin gathered the information used for the case studies on Automated Traffic Surveillance in Los Angeles and High Speed Ground Transportation. Karen also coordinated production of the Final Report. Brent Kerr assembled the information on Alternative Fuels for Transit Vehicles. And James Nolan assembled the information on cost-benefit analysis.

We would also like to acknowledge the assistance received from the School of Social Sciences; especially the help of Betty Simmes, Cheryl Larrson, and Tricia Joerger.

Encouragement and cooperation from the California Department of Transportation (Caltrans) has influenced the content and direction of the research. George C. Smith, Contract Monitor, and Kazem Attaran, Technical Monitor, provided constructive suggestions and have assisted us in obtaining reports from previous research contracts.

Linda R. Cohen
G.J.(Pete) Fielding

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EXECUTIVE SUMMARY

Every year the state receives hundreds of proposals to study California's transportation system and its challenges. Proposals are received internally from Caltrans and externally from universities and private consultants.

The Caltrans budget for research and development in 1991-92 was $17.7 million: $7.8 million for general research while advanced technology projects received $9.9 million. Of the total, $6.6 million was reimbursed by federal agencies.

The Legislature has questioned whether these studies are worthwhile, and the 1991-92 Budget Act contained Supplemental Report Language requiring that:

> "The Department of Transportation shall report to the Legislature, prior to budget hearings in 1992, on potential costs and benefits of non-IVHS research opportunities and how these activities might be incorporated into the NTDP program."

"NTDP" is the Department's New Technology Development Program which includes IVHS and non-IVHS research. "IVHS" is the acronym for Intelligent Vehicle Highway Systems.

The Department's report to the Legislature in 1992 indicated that new approaches were needed to predict the benefits and costs of research. The University of California, Irvine contracted to investigate alternative approaches. This report summarizes our conclusions and recommends a methodology for analyzing research.

A cost-benefit approach is recommended that appraises the contribution of each proposal to economic development and other transportation goals. An economic orientation is inherent in the recommendation as is the premise that research is vital to economic growth.

Research and Economic Prosperity

Research is the driving force behind this state's, and our nations's, productivity. It is through research that public agencies and firms acquire the knowledge that enables them to utilize capital investments efficiently.

Advances in knowledge were the single largest contributor to economic growth between 1929 and 1969. Investment in capital alone is insufficient; investment in research and development is required to demonstrate how labor should use additional capital to improve productivity.

Investment in transportation facilities can trigger productivity increases. By decreasing assembly and distribution costs, the areal scope of competition is enlarged. Management is challenged to improve research technologies for producing goods and services. Productivity increases result in real economic benefits.

The causal relationship between transportation, research, and productivity growth is vigorously debated by economists. The consensus is that there is a positive relationship. However, the effect is not as large as some advocates of transportation investment have suggested.

Transportation Research in California

California must continue to fund research in order to ensure development of new products and improved management. Only through such investments will California regain its preeminence in the nation's economy.

The rationale for the state's intervention is based upon two features of research: first, successful research contributes information beneficial to the entire economy, not only the investor, and second, there is always uncertainty about the commercial prospects of a research proposal, so without state assistance, there will be underinvestment in research.

The California Legislature has demonstrated great foresight in funding transportation research and development. For example, the Petroleum Violation Account was used to develop computer-assisted controls for traffic signals. This allowed traffic to flow with fewer stops and resulted in substantial energy savings. The Transportation Planning and Development Account has been used to analyze the seismic safety of bridges, as well as to demonstrate the effectiveness of intercity rail. And the Transportation Development Act has funded numerous management studies that have improved the performance of public transit agencies.

Grants to public agencies and the competitive solicitation of proposals are the usual manner for initiating research. However, the state should consider other options like prizes for successful innovations or market guarantees to encourage technological improvements in fields such as automobile emission systems and electronic license plates.

Research which addresses problems that uniquely or disproportionately affect California deserves emphasis. The size and diversity of the state, however, requires that a broad portfolio of research be considered in terms of real cost and benefits.

Cost-Benefit Analysis

Although research and development are vital to productivity in California, this does not mean that every proposal deserves funding. Quite the contrary, every proposal must be carefully evaluated to determine if the research will make a positive contribution to economic growth.

Cost-benefit analysis (CBA) is a technique that examines the merits of competing proposals. The criterion is the maximizing of monetary return (benefits) for a given amount of money invested (costs). Quantifiable estimates are preferred, but qualitative can be used to assist the ranking of proposals. CBA can also assist decision makers in choosing between proposals when total cost exceeds funding.

Although widely used in transportation, CBA is seldom employed correctly. Special care is required in order to avoid errors such as the failure to define a base case as a datum against which future improvements can be measured or to discount benefits. It has been estimated that fewer than one in five cost-benefit studies conducted in transportation are adequate.

The Net Present Value (NPV) method for CBA is recommended. NPV discounts both costs and benefits to present-day values. The discount rate must be decided in advance and applied uniformly so as to reduce future benefits to the equivalent of previous and continuing costs.

Only proposals with a positive NPV should be funded. And those with a greater NPV should receive a higher priority if there is insufficient money to fund all proposals.

Using NPV to create a fair and consistent appraisal of research proposals requires an agency to consider the following:

- o Appropriate goals for the research and how these relate to other goals sought by the agency.
- o Selection of an appropriate base case which includes the best available current practice rather than accepting the status quo as the basis for calculating benefits.
- o Duration of appraisal because the payoff from research is normally some years in the future.
- o Choosing a discount rate suitable for public investment when the probability of success is low.
- o Inclusion of all costs associated with proposal development, administration, and conduct of research. Costs in the form of negative benefits are normally deducted from benefits when they occur.
- o Appraisal of benefits to include direct savings as well as indirect effects on the economy achieved through the restructuring of activities.
- o Use of sensitivity analysis to test the influence of changing assumptions about discount rates and prices upon the ranking of proposals.

Appraising Benefits

Research presents special difficulties when estimating benefits. First, benefits are seldom captured by the research sponsor as the effects of technological change spread throughout the economy. And second, the market value of research may not be apparent for many years.

Forecasting techniques are required to estimate the magnitude of future benefits in transportation, but the value people place on the same benefit will vary. For example:

- o Value of time saved will vary by income of the traveler and the trip purpose. Work trips are valued more highly than recreational trips.
- o Estimates for the value of lives saved through improved safety or reduced pollutions vary from $1.5 to $9.0 million per life.
- o Environmental benefits and costs are difficult to appraise in terms of their value to individual citizens.

The wide discrepancy between high and low values placed upon transportation variables makes the forecasting of benefits difficult and controversial. The NPV method accommodates this by requiring that, first, the same values be used when appraising each alternative, and second, the results be tested for their sensitivity to changes in critical values.

The NPV method provides a consistent appraisal of alternative research proposals designed to achieve the same or similar goals. The values assigned are for comparative purposes only; they **should not** be used in predicting future revenue streams. Revenue analysis requires financial forecasting techniques that adjust demand for changes in price and quality of service.

Case studies

To illustrate the use of NPV when evaluating research proposals, two recently completed studies are analyzed as well as a statement concerning intended research. The purpose is to demonstrate how both evaluation of proposals and conduct of the research might be improved when NPV is used.

Research results from three modes were chosen, each with different goals:

1. Highway: automatic traffic surveillance and control in Los Angeles to reduce congestion.
2. Transit: alternative fuels for transit vehicles in Southern California to reduce hazardous emissions.
3. Rail: high-speed, intercity service using the proposed Anaheim to Los Vegas route as an example of how a research proposal should be evaluated in advance of funding.

All three studies produce helpful results. Our purpose is not to criticize the research. Rather it is to use the research to illustrate how NPV can be helpful.

Research for the development of the automatic traffic surveillance and the control system in central Los Angeles was conducted in advance of the solicitation of proposals to install the system. However, this information was not used effectively in the request for proposals. The estimated cost was $12.15 million to achieve benefits that were described as the reduction in stops and delays in the range of 13 to 17 percent. However, it is impossible to evaluate the proposed benefits because neither a base case is described, nor are the associated improvements in traffic management adequately explained.

Despite the deficiencies in the way proposals were solicited, the project has been beneficial. In a subsequent evaluation study, the City of Los Angeles indicates that annualized benefits exceed costs by a ratio of almost 10 to 1. This study discounts costs but not benefits. But when the same 8 percent rate of discount is applied to benefits the ratio is still 6 to 1. Discounting both costs and benefits reveals an annualized benefit of $4.5 million. By expressing the net present value, rather than a ratio, the magnitude of the project's contribution to economic efficiency is made apparent.

Research designed to evaluate alternative fuels has been conducted separately by the Orange County Transportation Authority and the Southern California Rapid Transit District. Each project assumes that an alternative to the diesel bus must be implemented prior to 2007. The goal is to discover the most cost-effective, alternative fuel.

Results from those two studies could have been more useful to transit agencies if both had used the diesel bus equipped with a particulate trap as their base case. By using emissions from a standard bus as the base case, comparative emission reduction from alternative fuels is exaggerated.

Implementation of high-speed rail service between metropolitan areas in California has been proposed. The goal is to reduce travel time. The case study demonstrates how CBA might be used to appraise the probable results from this research.

CONCLUSION

The objective for this research has been to develop a methodology by which Caltrans may evaluate research and develop a portfolio of proposals for consideration by the Legislature. Increasing productivity has been emphasized as the priority goal because research should be appraised in terms of its contribution to economic efficiency.

The NPV methodology is advocated because it provides a consistent way to evaluate alternative proposals in terms of current dollars. Proposals can be ranked in terms of the magnitude of benefits, or they can be placed in an array viii representing their contribution to other goals and various modes. This latter use of NPV will facilitate the selection of a portfolio of research proposals.

Agencies utilizing NPV will be able to rank alternative proposals in terms of economic efficiency as well as other desired goals. This will assist decision makers to arrive at informed and economically justifiable decisions. And this is what economic analysis is all about-- the allocation of scarce resources to their best possible use.

CHAPTER 1

TRANSPORTATION, PRODUCTIVITY, AND ECONOMIC PROSPERITY

Transportation has been a major influence on economic development in California. Construction of ports, railroads, roads, airports, pipelines, and transit systems has provided employment and allowed industries to compete nationally and internationally. These benefits became apparent during the 1970s and 1980s as the state capitalized upon investments initiated during the 1960s. Between 1975 and 1985 annual output (gross state product) grew at an annual rate of 4.1 percent while the U.S. economy was growing by only 2.9 percent a year. California surged ahead to unprecedented success, becoming the sixth largest economy in the world.

All this has now changed. The transportation infrastructure network is virtually complete; an increase of only 4 percent in lane miles is contemplated for the state highway system during the 1990s. The industrial complex of defense, aerospace, and electronics is being displaced by employment in services, commerce, entertainment, and tourism industries for which transport of freight is less important. Los Angeles County, for example, led the nation in manufacturing-related employment in 1985 with 900,000 manufacturing workers, but the county is now losing manufacturing plants to both neighboring states and foreign countries. These changes are starkly reflected in the gross state product which declined by 5 percent in 1991.

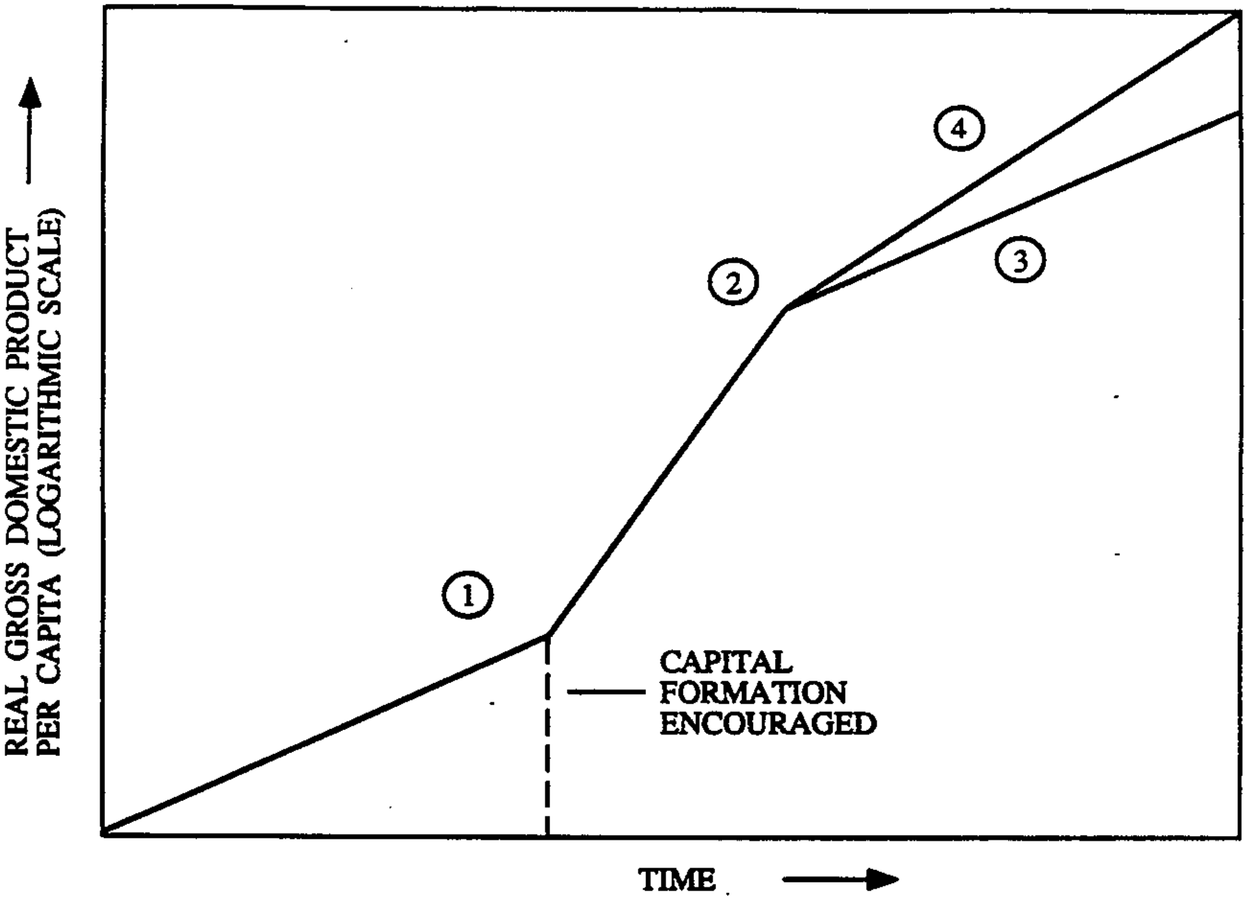
Transportation remains important, but its role in the economy has shifted. For many years, expansion of the states transportation network dominated economic activity, but now maintenance requires the greater proportion of expenditure. And in the future, California will have to seek productivity improvements through more efficient use of existing infrastructure, rather than relying on network expansion.

This chapter analyzes the contribution of transportation to productivity and economic prosperity. The previous importance of capital investment in infrastructure is acknowledged, but emphasis is placed on the current need to improve productivity growth through more efficient use of existing facilities. The thesis is developed in three sections: the first explains the role of capital investment, the second outlines the crucial role of research, and the third discusses the impacts of transportation on a service-oriented economy.

CAPITAL INVESTMENT AND ECONOMIC GROWTH

Achieving higher growth rates requires increased public and private capital investment. Ralph Landau (1988) illustrates the crucial effect of capital formation on the economy (Box 1.1). As long as the rate of capital formation is constant (Curve 1), labor force improvements and adoption of new technology take place at a constant rate. However, when capital formation is encouraged by economic policy, the rate of change accelerates (Curve 2). The economy does not return to the former rate of growth (Curve 3) afterwards, but continues to increase as research develops new technologies and operating practices to utilize the new equipment and facilities (Curve 4).

Landau makes disturbing comparisons between the meager increase in capital per worker in the U.S. since 1964 and a growth rate of less than one percent per annum in labor productivity. West Germany and France have had capital investment rates roughly twice those of the U.S. and have enjoyed about twice the growth in labor productivity. The results for Japan are even more startling. Between 1964 and 1984



Box 1.1: **RATE OF ECONOMIC GROWTH** is constant (1) as long as capital formation (the construction of new factories and production equipment), labor-force improvements (the training of workers) and technological change (the development of new inventions take place at a constant rate. When capital formation is encouraged by changes in a nation's economic policy, the growth rate increases (2), since the nation acquires a greater capacity to supply goods and services. If there are no interactions among the rate of capital formation, the quality of the labor force and the pace of technological change, the economy returns to its original rate of growth in the long term (3). But if increasing the rate of captial formation accelerates the rate of labor-force improvements and stimulates technological innovation, there may be a longer-term increase in the rate of growth (4). (After Landau, 1988, p. 47).

the average annual growth rate of gross capital per worker was 8.8 percent with the result that productivity increased by 4.6 percent annually.

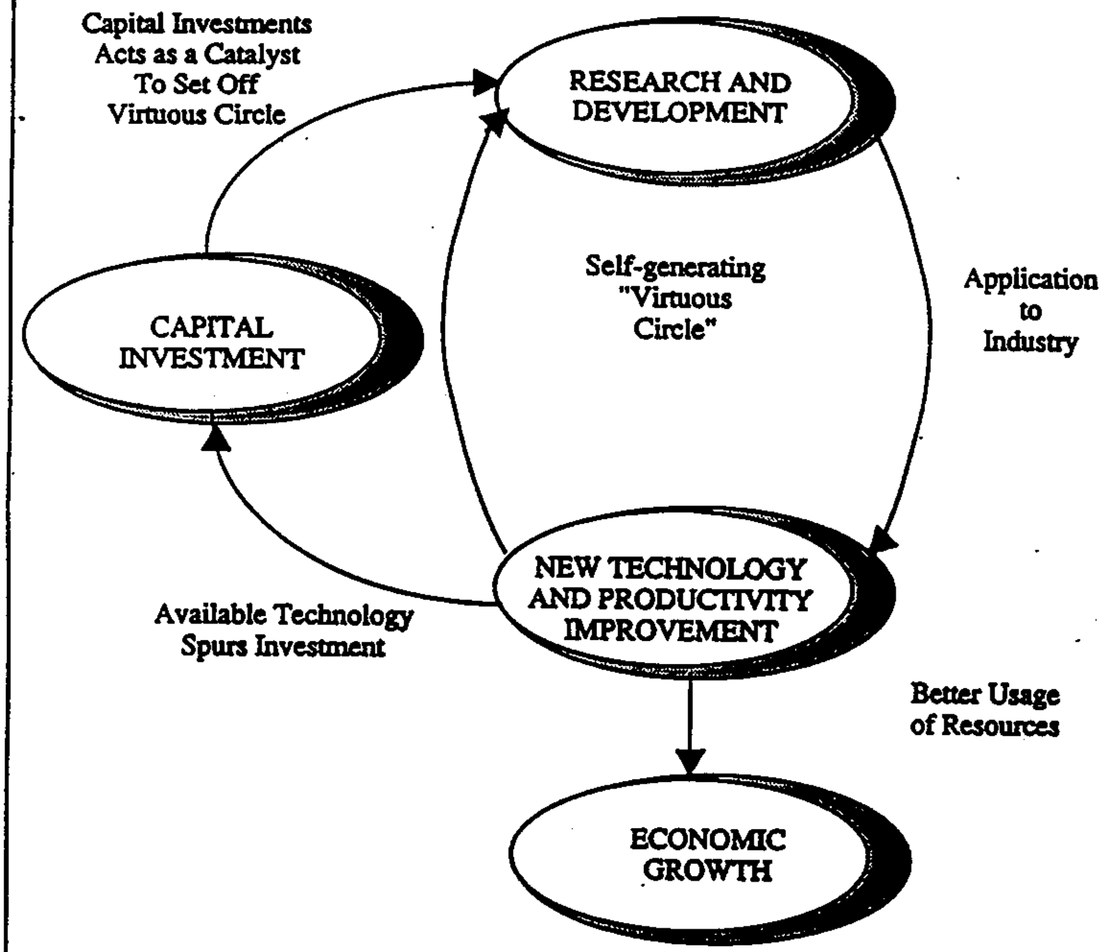
A similar pattern of capital disinvestment is apparent in U.S. transportation. Between 1970 and 1989 capital investment in all forms of transportation declined from $62.00 to $52.00 per capita. Net investment also declined.

Failure to invest in transportation creates a loss in productivity through the additional travel time required as the result of congested or poorly maintained facilities. Employees waste time commuting, and the cost of assembling and distributing goods and services increases. And it may have an even wider, negative influence because investment in transportation triggers a cycle that stimulates private as well as public investment throughout the economy.

Productivity and prosperity

Governmental investment in transportation is based upon public good and externality principles. Unless there is congestion, everyone enjoys similar benefits from using transportation facilities, and increased accessibility reduces costs or raises the quality of goods and services throughout the economy. The state provides airports, highways, and ports, and taxes all users for the benefits they enjoy. Achieving these benefits, however, requires a partnership between government and private business; public agencies provide the facilities and private firms invest in aircraft, trucks, automobiles, and ships that utilize these facilities. Public improvements spur private investments that far exceed public investments.

The rate of both public and private capital investment influences productivity. Together they positively affect output through scale economies: manufacturing



SOURCE: David Lewis, Daniel Hara and Joseph Revis, The Role of Public Infrastructure in the 21st Century, Special Report 220, Transportation Research Board (National Research Council), 1988.

Fig. 1.1 The "virtuous circle": economic growth through capital investment.

the development and maintenance of transportation infrastructure, offers one of the most effective catalysts for productivity growth. Innovations from research spur better use of resources; implementation occurs through new facilities and superior operating modes that can improve productivity and contribute to economic growth. And the investment of additional capital prompts the cycle of new research and improved technology. However, Lewis, et al., caution that not all transportation investments are beneficial. They counsel decision makers to undertake research which evaluates the net benefit of proposals before investing capital.

Lasting benefits from transportation are achieved through increased productivity. Travel time reductions may benefit commuters, and special services may satisfy the travel needs of individual groups, but the sustaining benefits are those which boost productivity by reducing costs or raising the quality of goods and services.

IMPACTS OF TRANSPORTATION

Improvements in transportation can be analyzed in terms of **efficiency and social, environmental, and economic impacts** (Fig. 1.2). **Efficiency** identifies benefits achieved through reduced cost and travel time. **Social and environmental** impacts include improved mobility and safety, and environmental consequences. **Economic** benefits are those associated with changes in personal, regional, and sectorial income. These categories are not mutually exclusive as improvements in efficiency are required to attain economic benefits.

Efficiency benefits are the easiest to identify and measure because they can be equated with travel time savings. Social, environmental, and economic impacts are

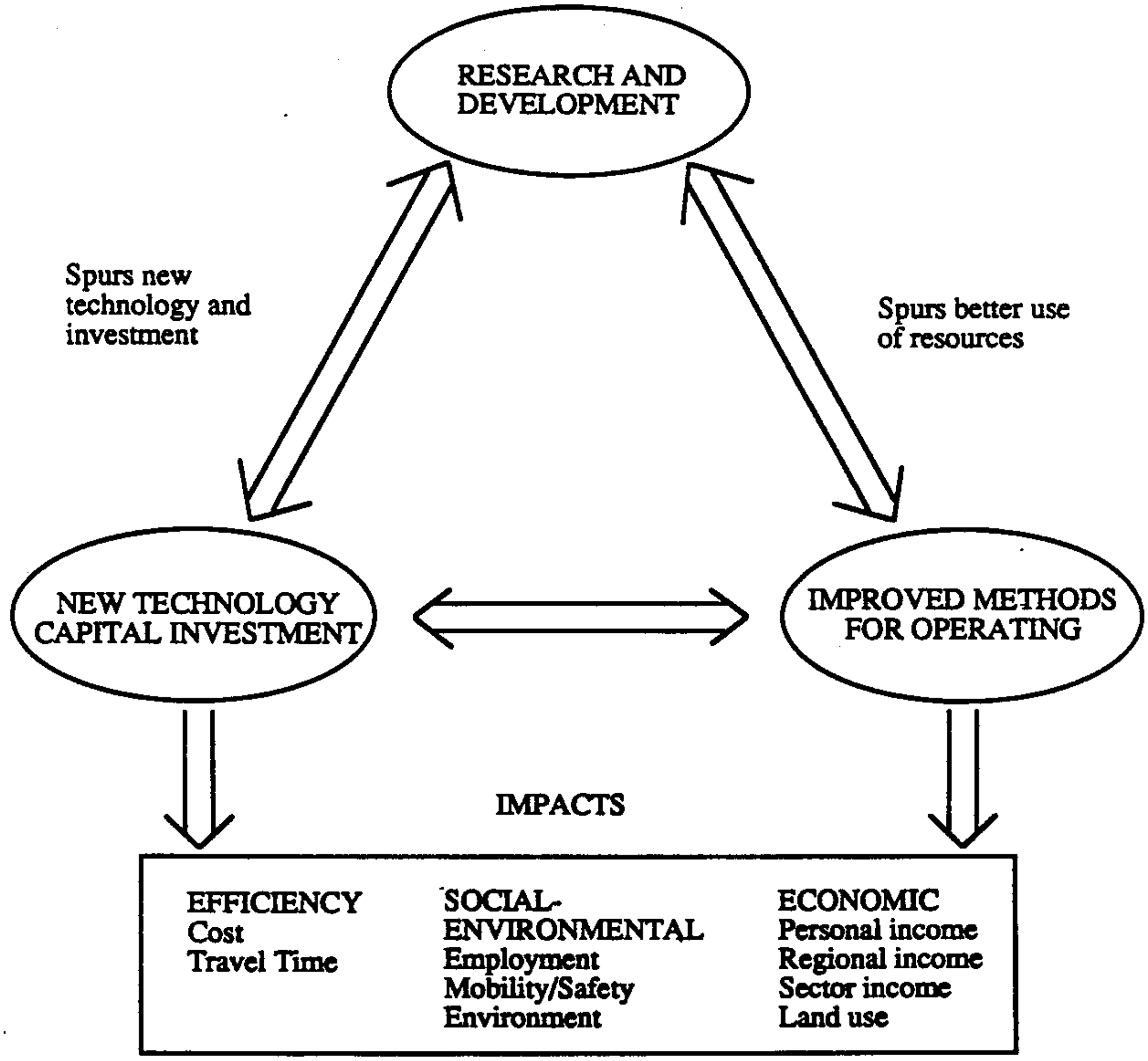


Figure 1.2: The productivity triangle: research and development spur development of new methods for operating transportation as well as new technology and capital investment. New technology demands new operating methods and vice versa so that a triangle of continuing improvement and new research develops. The resulting increased output per employee stimulates economic growth.

more difficult to quantify. Also, the impacts are frequently obscured by controversy between interest groups when local life-styles are adversely affected by proposed regional improvements. Additional research into life-style impacts (what the economist refers to as welfare impacts) is required, and new methodologies incorporating risk need to be considered. For example, how should the risk of using diesel or more expensive electric locomotives be evaluated when analyzing the benefits associated with commuter rail in Southern California? Is the reduction in air pollution worth delaying implementation of commuter rail service, or could the savings be more effectively invested in air pollution reduction elsewhere in the region? Additional research into transportation impacts is required to identify benefits and costs and to express them as economic variables.

Economic impacts

Overall benefits of transportation improvement are frequently obscured. They are normally expressed as the number of jobs created or the number of purchases from other sectors, whereas it is through increased productivity that real economic benefits are achieved. In addition, the influence of transportation upon personal and regional income and land use is usually omitted because of the time and cost required for this analysis.

Promotional literature associated with transportation improvements boasts about the number of jobs that will be created. If this logic is followed, workers would be unemployed at the conclusion of construction. A counter argument goes as follows: if the taxes had not been collected to pay for the improvement, individuals would have spent their money and created private demands for additional employment. Only in regions of chronic unemployment can a genuine case be made for transportation investment creating jobs (Lewis, 1992). The classic misuse of this argument is apparent in California where metropolitan counties increase sales taxes to improve freeways and rail transit. The case for increasing the sales tax is normally accompanied by claims about the employment benefits. However, the number of jobs are not adjusted downward due to the private employment that might have occurred had the money not been taxed away by local government.

The American Public Transit Association (1983 and 1984) used similar, although more sophisticated, analyses to demonstrate the economic benefits derived from transit capital and operating spending. Employment impacts were estimated based upon each $100 million of expenditures in 1979 (Table 1.2). Operating expenditures were shown to create 20 to 30 percent more employment than capital projects. The sophisticated, input-output model developed by the U.S. Department of Commerce was used to estimate the sum of direct, indirect and induced impacts of transit capital and operating expenditures as business revenues in 38 sectors of the economy. One dollar spent on transit was estimated to create a $4.29 increase in household income and a $3.07 increase in business sales. However, neither publication gives more than brief mention to the influence of transit on the overall economy. For instance, metropolitan areas rely on public transit to transport employees and patrons. As is apparent during a transit work stoppage, most central cities cannot function without the congestion relief provided by buses and trains. But this contribution to productivity and economic growth is overlooked in the aforementioned publications.

A more thorough assessment of overall benefits is made by examining the productivity increases derived from transportation investment. Elimination of congestion reduces travel time and translates into real improvements in

Table 1.2: Employment Impacts per $100 Million Expenditure in 1989

Expenditure	Transit Capital Rail Starts	Transit Capital Rail Modernization	Transit Capital Bus Facilities	Operating Expend.
New Construction	934.86	258.94	464.26	0
Mainten./Repairs	15.22	1085.55	18.79	11.49
Motor Vehicles	93.16	241.60	605.81	77.30
Wholesale Trade	115.20	140.35	260.76	23.00
Business Services	1124.76	405.29	232.82	236.32
Transportation	131.09	91.43	119.73	3165.55
Insurance	17.97	20.16	16.36	154.70
Other	947.25	969.70	1430.40	394.65
Total	3379.60	3213.02	3148.93	4063.01

Source: American Public Transit Association (1983) productivity, allowing firms to reduce costs. Improved productivity stimulates the economy and encourage the hiring of additional employees. For example, a supermarket chain owning stores and warehouses in Southern California will benefit from highway improvements through reduced travel time for trucks. Even larger benefits could be achieved, however, if reduced and more predictable travel times allowed the company to restructure warehousing to fewer locations. Larger and more efficient warehouses would reduce cost and increase productivity. These benefits have been described by Quarmby (1989) for the Sainsbury supermarket chain and adapted as a case study by Lewis (1992) (Box 1.2).

The influence of transportation on manufacturing can also be illustrated graphically (Fig. 1.3). The cost of shipping output increases with distance so that the factory maximized profit with output A. If transportation is improved, not only is profit per unit at A increased, but also the market area is enlarged; the quantity/price curve moves to the right. The new maximum profit output is at B. Additional capital and labor must be invested to achieve output B. And in this way the initial investment in transportation multiplies its influence throughout the economy. Competing factories, observing the increased profit, may also invest capital and labor in anticipation of increasing the size of their market share. Price might decrease as a result of competition, allowing more consumers to enjoy the output at or below the original price.

National productivity

There is also a relationship between national productivity and investment in public infrastructure including transportation. The decline in productivity has been widely identified as one of the most urgent dilemmas facing the nation. Total

BOX 1.2

CASE STUDY

Accounting for Industrial Productivity Benefits Associated with Major Network Improvements

Sainsbury's, Britains largest supermarket chain, considered the impact of a road network improvement on food distribution. The road improvements are seen to have two impacts. One is to reduce the driving time required for trips. The second, as a result of the faster driving time, is to permit the firm to make a major structural change in logistics, namely to reduce the number of its depots from 6 to 5. The closure of depots requires an increase in the number of miles travelled of 9.5%, but the additional cost is outweighed by the savings from closing a depot. Savings in closing the depot come from reduced inventory holdings and economies of scale in handling increased volumes of goods with one less depot.

The firm looked at the measurement of benefits in two ways. Case A, counts only the savings in driving time and associated costs, assuming that the structure of the firm's operations remains the same. Case B, considers the additional impact from the reduction in the number of depots.

Savings from Improvements in Road Network

	Per case handled
	British Pence (p)
Case A	
- Transport savings without restructuring	1.3
Case B	
- With Restructuring	1.6
Marginal volume benefit	0.5
Stock saving	2.1
	0.5
Less extra transport cost	1.6
Total	0.3 over
- *Extra benefit* over transport savings	1.3p = 23%

The analysis indicates that true benefits to the firm, including the benefits of restructuring, are 23 percent higher than those captured by conventional Benefit-Cost practice which would measure only the direct benefits from faster travel time.

Formal theoretical extensions of the traditional Benefit-Cost framework developed for the Primer confirm the validity of the Sainsbury's analysis, (see Technical Report). Other tests conducted in the Technical Report indicate that failure to account for productivity impacts can understate the true economic of major improvements by more than 100 percent.

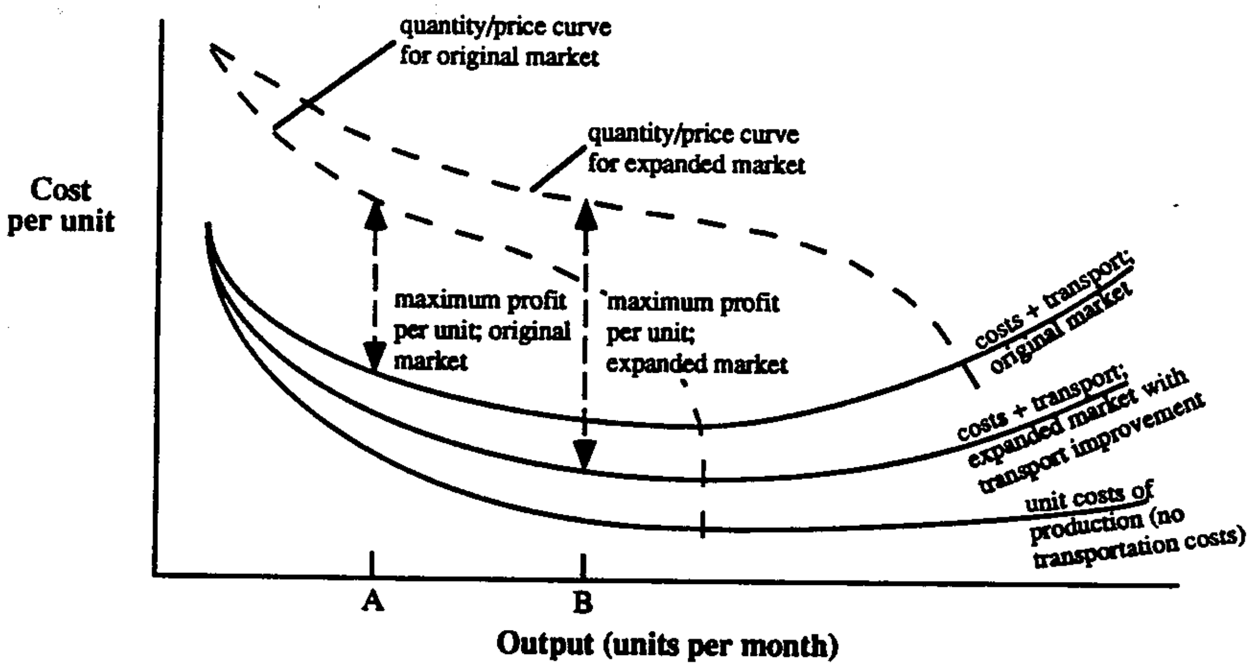


Fig. 1.3: Influence of reduced transportation cost on demand and output for manufacturing.

factor productivity in the private, non-farm, business sector declined from an annual average rate of 2.0 percent between 1950-70 to 0.8 percent between 1971-85 (Aschauer, 1989). Recent numbers are somewhat better, but still well below the achievements of the 1950s and 1960s. Although economists have concluded that a variety of factors have contributed to the slowdown, Alice Munnel (1990,4) writing in the New England Economic Review makes a case for the notion that "the stock of public infrastructure as well as the stock of private capital may be the key to explaining changes in output from the private sector." She concludes that the slowdown in the 1970s and 1980s was associated with decreased public investment in streets, highways, mass transit, airports, and water systems (Fig 1.4).

Other economists have disagreed with the significance that Aschauer and Munnel have placed on the role of public investments, especially those in transportation. McGuire (1992) reviews the opposing arguments and explains that the influence is difficult to isolate because four transformations are taking place concurrently:

- changes in production process
- changes in the structure of the industrial sector
- shifts in the location of various economic activities, and
- the increasing importance of the service sector

Failure to account for these transformations helps to explain differences in the results. McGuire concludes, however, "a consensus that public capital has a weak positive effect on private economic activity is emerging among the researchers involved." As the majority of studies indicate that investment in transportation has a small positive, although weak, effect on overall productivity, this may help to explain the decline in productivity growth. Transportation investment did not

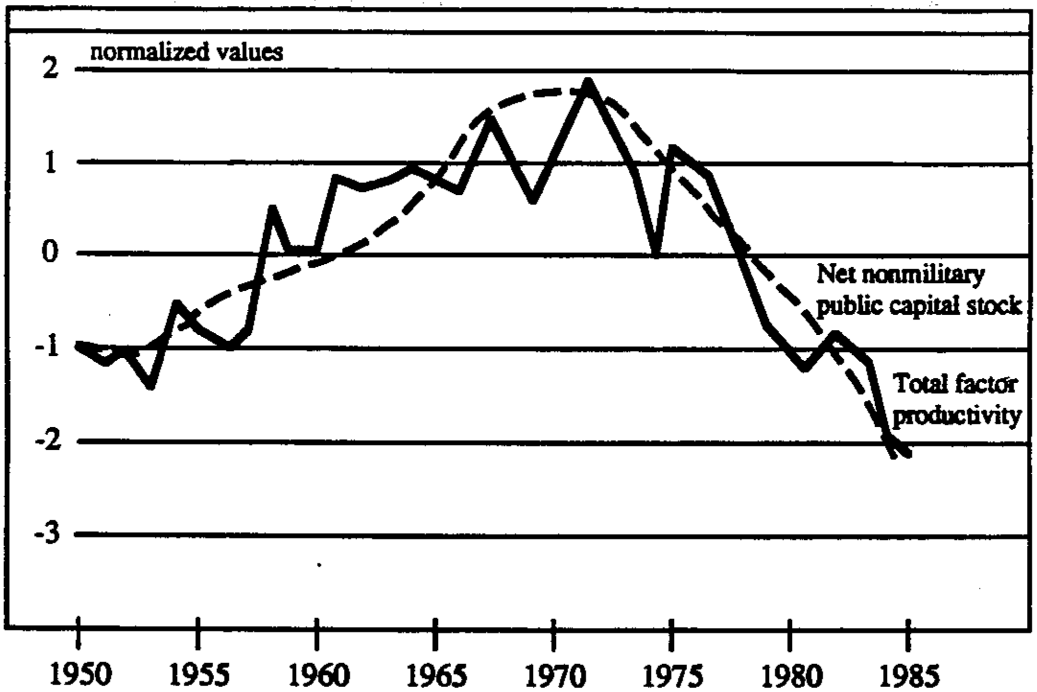


Fig. 1.4: Net nonmilitary public capital (adjusted for the effects of time) and total factor productivity (adjusted for the effects of time, private input, and capacity utilization; annual data 1949-85; sample size = 37. (After Aschauer, 1989, p. 196.)

keep pace with depreciation between 1970 and 1989, causing the net stock of transportation infrastructure to decline.

International comparison

Comparison between developed and developing nations illustrates the crucial role of infrastructure in economic development. In countries where transport facilities are poor and service unreliable, development is concentrated in major cities. Throughout most of the rest of such a country, a subsistence economy predominates with few opportunities for economic specialization because of the lack of adequate transportation competition.

Mexico suffers as a result of inadequate infrastructure. There are 27,600 kilometers of road per million population and the once proud rail system has insufficient equipment to cope with expanding demand. Most of the 20,000 kilometer national railroad is without electric signals, cannot carry the 120-ton load of a modern hopper car, and is woefully short of engines and rolling stock. More than one-fifth of the 84 million population dwells in Mexico City where 36 percent of the gross national product is produced. There are substantial diseconomies created by this level of concentration, but this does not discourage migrants because insufficient employment is available elsewhere. Attempts to develop other regions have not fared well because of inadequate infrastructure. The exceptions are based upon local resources in mining, agriculture, or tourism. Malquiladoras cluster in border states, not only because labor is available from migrants, but also because proximity to the U.S. provides access to superior highway and rail systems. Economic activity is concentrated in the largest city because inadequate infrastructure prevents rival cities and their industries from achieving economies of scale in production. And without infrastructure improvements, Mexico will not obtain full economic advantage from the proposed North American Free Trade Agreement.

CONCLUSION

Development of transportation infrastructure has played a crucial role in the economic development of California. Without railroads, interstate highways, and airports, California would have remained a high-cost, marginal area for both supply and demand reasons. Prior to 1910, manufactured goods had to be imported from Europe and the Northeast, and wages had to be high to compensate for the high cost of living. Improved access to national and international markets and raw materials allowed industries to specialize; to become more productive, to compete internationally, and to import those goods produced more efficiently elsewhere.

Although transportation facilities have assisted California, real growth in personal income has resulted from improved productivity when capital invested in public and private facilities has increased labor output in agricultural, manufacturing, tourism, and service industries so that they could compete nationally and internationally. Capital investment plays a crucial role; it triggers a "virtuous circle" by stimulating the introduction of new technology and improved operating methods.

Investment in transportation alone is not sufficient. Faster growth requires more investment in machinery, equipment, education, and training in order to take advantage of the transportation improvements. The challenge is to determine which investment, and in what sequence, will be most beneficial.

When the planned transportation network is virtually complete, as it is in California, improvements come primarily from innovations in design and operation. In this respect, R&D is crucial because it prepares managers for new ideas and encourages the testing of potentially valuable techniques. Not all innovations are viable; each needs to be evaluated, first for consistency with agency goals, and second to assess proposed benefits against anticipated costs.

CHAPTER 2

TRANSPORTATION RESEARCH IN CALIFORNIA

The economic case for public sponsorship of research and development (R&D) is generally accepted in the United States. The federal government directly spends over $70 billion in R&D annually and pursues a variety of other policies, from tax credits to antitrust exemptions, to promote private investment in research and technology development. The Caltrans budget for research in 1991-1992 was $17.7 million; $7.8 million was made available for general research while advanced technology projects received $9.9 million. Of the total, $6.6 million came from federal agencies. Caltrans also provided state funding to local agencies and the University of California to match federal grants for transportation R&D.

The case for state policies to promote R&D has received little attention. The purpose of this chapter is to explore the arguments for a pro-active government role in R&D and to give guidance on where and how the state government might concentrate research activities in transportation. Our recommendations follow from integrating three aspects of the problem, which are addressed in turn. First, we consider the different categories of activities that comprise research. Second, we discuss different reasons why the public sector should support research. Third, we identify several strategies that are available to a state agency for the support of research. The chapter concludes with a set of guidelines for prioritizing state-supported research.

THE CHARACTER OF R&D

Research is usually characterized as basic, applied or development. The critical distinction relates to how close research activities are to a non-researchapplication. The defining characteristics of **basic research** are that it is undertaken without any particular commercial product or process as a goal, and that its results may be applied to a wide variety of problems. Due to its potentially broad applicability, basic research is sometimes referred to as generic. **Applied work** undertakes to use and extend basic research for a particular purpose, but is still pre-commercial. At this stage a number of alternative strategies might be considered for development; in part, the purpose of applied research is to narrow down the options before undertaking expensive development activities. Typically, **development activities**, which are intended to bring a product or process to market, are far more expensive than either basic or applied research, for it is at this stage that prototypes and demonstration facilities need to be built.

Most projects fit only loosely into this classification. Development projects often run into snags that require applied (or worse, fundamental) research. Indeed, this is a major source of cost overruns in pilot programs that involve sophisticated new technology. Basic science is often motivated by applied problems, even if the application appears remote. Moreover, in some high tech fields, notably, biotechnology, even basic research results can have near-term commercial value, and most major research universities have active patent offices.

Nevertheless, because of several critical differences, these categories are useful in the formulation of government policies. The first difference is the nature and extent of uncertainty. Basic research results are typically very and difficult to predict, and many alternative lines of inquiry may be appropriate for pursuit. Applied research is characterized by uncertainty as well although researchers usually have a better idea of which paths are most promising and where the paths lead than for basic research. A second difference is cost: basic research projects are generally far less costly than either applied or development work,development costs overwhelm the other categories. The third difference is that the time horizon varies. Basic research cannot be expected to pay off until years in the future; applied and development programs usually have shorter time horizons. Because of these differences, the nature of problems in the private conduct of R&D varies for basic, applied, and development activities, and hence the rationale and appropriate strategies for government intervention vary as well.

PRIVATE MARKET FAILURES: THE CASE FOR PUBLIC SUPPORT OF R&D

Economists justify government support for research on market failure arguments. The argument is that firms are not sufficiently rewarded for undertaking research activities because their profits may be substantially less than the social value of innovations. This argument rests on two attributes of research: first, a successful project results in information about new products or processes, and second, substantial uncertainty exists about the commercial prospects of a research enterprise.

Information, once it becomes public, can be used freely by people other than its discoverers. Sometimes just the knowledge that a product is feasible gives an advantage to potential competitors. The first characteristic of research implies that an innovation can be copied at much less expense than the original research or development work, so that competing firms can reap profits from the invention at a lower cost than the original innovator. This is known as the "appropriability problem"; researchers may be unable to appropriate the full returns from an invention. Indeed, it may be in everyone's interest to be a copier rather than an innovator. As a result, research will receive less attention than it should, and in some cases it might not be performed at all.

The second attribute, uncertainty, is more subtle. The problem is not just that uncertainty over profits exist, but that risks to individual investors may be much greater than for society as a whole. When private risk exceeds social risk, firms underinvest in research activities.

Use of public resources to subsidize research is a common response to these market failures. However, while lack of appropriability and uncertainty are characteristics common to all research activities, they are particularly problematic in some areas. A closer examination of market failure arguments can yield more useful policy recommendations.

Appropriability

Economists define appropriability as the degree that a firm can profit from its own research innovations. Two issues determine the extent to which innovators profit from an invention: the nature of the innovation and the structure of the industry. When research yields a specific product, an efficient battery, i.e., the innovating firm may be able to patent the product. In this case, the firm can choose to exclusively market its invention for some years and fully recoup its development expenses, or it may choose to license the technology to other companies for a fee which similarly covers research and development costs. Alternatively, if the research results in more fundamental knowledge, i.e., about chemical properties of compounds that can be used in the construction of batteries, then patenting is not only more problematic, but also socially inefficient. The first problem arises when knowledge of chemical properties is generally available. Under these circumstances, its use is difficult to trace and charge for. In addition, the knowledge itself may not produce the battery. Further development work, perhaps by researchers with different fields of expertise from the original innovators, may be necessary to produce a commercial device. In this case, if the knowledge is kept secret so as to protect its value, society suffers because commercial opportunities are not exploited. Thus, full and free dissemination is in the social interest. In general, the more basic the research, the further away it is from commercial application, the less effective or desirable is the patent policy, and the greater the need for direct public subsidies to encourage research.

Industry structure relates to this issue as follows. Firms fail to fully capitalize on inventions when competitors succeed in using it without paying for their share of the research costs. When firms compete for customers, i.e., the industry is subject to product market competition, a new process that reduces product cost will cause the product's price to drop. In other words, none of the firms benefit; rather, customers are the prime beneficiaries of the research. Alternatively, if firms do not face product market competition, they can recoup at least some of the development costs. Thus, it is important to distinguish between products sold in competitive and noncompetitive industries. Regulated utilities are an example of noncompetitive industry. Electric utilities base their retail prices on decisions made by public utility commissions rather than competitive market forces. Thus, the state has an alternative strategy for funding research in regulated sectors. It can allow prices to remain at levels that are higher than costs after the innovation is commercialized, or it can raise prices to support research. This latter strategy has been proposed to amortize the cost of developing electric vehicles for California (L.A. Times, 1-8-93). Similarly, the state can encourage toll road authorities to conduct research by establishing a policy that allows them to recoup research costs in higher (regulated) tolls or a higher return on equity. Lack of appropriability need not present as great a hurdle to the conduct of R&D in regulated industries.

Unless the firm is a monopolist, and few industries exist in the United States that can be described as sole sellers, then lack of product market competition does not fully resolve the problem of research benefits being gained by firms which did not fund the research. Without patent protection, benefits are still captured by all firms, not just the innovating company. The potential innovator will still underinvest in research, and hence the public sector still has a role in funding research activities. This issue, which is usually described as "spillover", has been receiving increased attention at the federal level as the world economy has become increasingly integrated. In brief, federal subsidies have spillover benefits not just to domestic firms, but to foreign firms as well. While the case is clear for subsidizing a domestic industry, it is more controversial at the international level.

Clearly, the problem is even more applicable at the state level, for innovations subsidized by the California government will benefit firms and consumers in other states. Note that the reverse process can also apply: the state may be able to receive spillover benefits from research performed by other states or by firms subsidized by other state governments. The extent of spillovers, however, is related to the nature of the problem that research is addressing. Some transportation problems are relatively unique, or perhaps particularly pressing within California. In this case, waiting for results from projects outside the state is likely to be a futile strategy. However, the conclusion does not immediately follow that such projects be prioritized for state support. If the problem is fairly local, spillovers outside the state will be smaller and local benefits more closely aligned to total benefits. In other words, less of a market failure results from lack of appropriability. Justification for state support then depends on the number of potential competitors in the industry and the market structure of the industry.

For research problems that are not unique to California, it is tempting to fall into the same market failure trap at the government level as at the firm level: to wait for other states to fund research and then take advantage of the results. A closer examination of the research process suggests that the argument is flawed in practice.

Studies of technological innovations conclude that in order to innovate, a firm must have considerable technological expertise. It must be able to recognize the potential value of a new product or process, and usually it must modify an innovation to produce a product with commercial value. Practically, the implication is that innovating firms need to maintain at least a base level of research: they need to employ scientists or engineers who are aware of innovations produced elsewhere, who can recognize the potential applications, and who are able to modify them to fit into the capabilities of the parent firm. Copying a technology is not a free activity; much of the successful industrial policies of developing countries have been devoted to precisely this activity. Copying requires time, effort, and money. Thus, while California need not, and should not, attempt to independently pursue all lines of research, if it is to make use of technological advances elsewhere, it must pursue an active research and development program of its own.

This process is known as technology diffusion. A relevant example is in the diffusion of dial-a-ride (DAR) technology in California. DAR buses were first introduced to California by the Orange County Transit District (OCTD) in 1972 (Fielding and Shilling, 1974). The District had a small, professionally-trained staff. They had both training and expertise to recognize the benefits of DAR buses, yet were not burdened by operating responsibilities. The innovation had been developed and tested by UMTA and the State of New Jersey in Haddonfield; OCTD used their knowledge to replicate the innovation in La Habra, California, and after the service potential was demonstrated, expanded DAR throughout Orange County. Other communities recognized the appeal and the innovation spread throughout California.

Furthermore, successful research is associated with a high level of serendipity. It is not possible to predict in advance what strategies are likely to pay off. This is especially the case with important inventions, and the history of technical advance is replete with examples of inventions arising from unlikely sources. Very few research projects genuinely duplicate other efforts, and the more lines of research that are investigated, then the more likely is success. Thus, even if research in a field is conducted in other states, pursuing additional projects here raises the probability of success.

The importance of these factors varies with the nature of the research project. The further a project is from a commercial application, or the more basic or generic the activity, the greater the justification for investigating the problem even if other research groups are looking at it as well. The more sophisticated the technology, in a scientific sense, the more important it is to have local expertise. Thus, as a general guideline, state support for research is most critical for leading edge applications or for basic science activities. However, as the DAR story demonstrates, the spillover value of expertise can be substantial even at the demonstration end of the research process.

Uncertainty

Uncertainty permeates R&D programs because the likelihood or extent of the technological success is difficult to anticipate. In addition, the actual application of research (the product area) may be imperfectly known at the research stage. If the ultimate product is unknown beforehand, it follows that the size of the market for the application, and whether it will exist at all, is subject to uncertainty. Finally, uncertainty exists about who will profit from the research results. Thus, research is not only risky, but it is likely to be far riskier than other investment activities that firms undertake.

Uncertainty over basic research activities can be mitigated by simultaneously pursuing multiple strategies. Just as the risk of stock return variations can be reduced by investing in a portfolio of companies, so is the risk of research lowered by sponsoring multiple projects. As a result, research is less risky to society, which benefits from average success rates from all projects, than to firms who rely on a smaller set of projects.

Research on alternative fuels illustrates the desirability of undertaking basic research on multiple sources. Diesel, propane, methanol, natural gas, and electricity each have their advocates. Their relative energy efficiency is known, but we do not know what pollutants result from combustion, how these gases interact in the atmosphere, or what the spillover effects will be on other industries if demand is increased in transportation. Basic research on alternative fuels is required, but advocates have no incentive to conduct this research. It is too risky unless sponsored by governmental agencies. And until the basic research is complete, applied research on the costs and benefits of different fuels will be inadequate.

Empirical studies have found that in the United States bigger firms do not on average invest more in risky research projects than do small firms. The explanations for this phenomenon have centered on bureaucratic hypotheses. Management structures in large firms appear to impose effective risk avoidance on the activities of their research groups. Thus we cannot conclude that uncertainty poses more of a disincentive to research investment in small firms than large firms: both may need help from the public sector in overcoming an uncertainty-based market failure.

The conjunction of uncertainty with the potential for research benefits to be gained by firms which did not pay for them yields a further market failure in the private provision of research. When the results of research are unknown, there is a possibility that they will yield a product that will be of value to someone else. In the worst case (for a firm), the results might profit a competitor who because of the appropriability problem, will not need to compensate the innovator. Society, the sum total of all firms, has nevertheless benefitted, but not the innovating company. Thus, uncertainty can create a potential discrepancy between private and social returns, and provides yet another rationale for public subsidies for research.

Thusfar, this section has suggested that uncertainty in research means that government should concentrate resources in subsidizing basic research activities.

Here the discrepancy between private and public returns are likely to be greatest, and we concur with the bulk of analysis that concludes that a direct subsidization role for government is likely to be most beneficial in the field of basic research. However,

uncertainty exists in applications as well, relating primarily to the potential loss of a large sum of money. Consequently, the government can also play an important role in encouraging development, although it may be different from standard funding of R&D. A different public strategy designed specifically to address problems in financing risky development may be appropriate.

Government goods

By government goods we mean any product whose use is determined, or significantly affected, by the public sector. Most infrastructure, including roads, is included in the category as well as other goods and services provided by government: schools, libraries, universities, police and fire departments and so on. In addition, the government is a major consumer of some products, and can account for an important part of the market for products like communications equipment or office machinery. Third, the government regulates the use of some products to such a degree that government policies are critical to determining their commercial value. For example, the use of air pollution and noise abatement equipment is contingent on government regulatory policies.

It is important to distinguish government goods from other products in assessing R&D policy for two reasons. First, because the public sector is instrumental in the use and, hence, commercial value of these goods, a range of policy options for encouraging R&D through market-pull policies is available to government that is not feasible for other products. We discuss these strategies below. Second, the market failure problems discussed above can be exacerbated for government goods so that ameliorating policies may be especially important.

Uncertainty is compounded for private companies who might be interested in improving the technology of government goods. Public decisions reflect nonprofit oriented goals; in addition, they depend on constraints not present in the private market. Purchasing decisions can reflect political imperatives: maintaining employment in a certain area, for example, or "buy American" requirements. Regulatory requirements that might be critical for establishing a market for products can shift for reasons unrelated to the actions of suppliers. For example, strict environmental requirements are sometimes relaxed during economic downturns or might be modified in response to lobbying efforts by politically powerful interest groups. Furthermore, personnel shifts, either administrative or legislative, are frequently accompanied by changes in policies. Different administrations may place different priorities on conflicting public goals: for example, the desire to spur economic growth versus avoiding environmental harm caused by development. All of these factors raise uncertainty for firms so that they become reluctant to invest in research.

Underinvestment in research for government goods arises because government cannot commit to a set of policies over time. Market failure is likely to be most severe when the time horizon of the research project is long, for in this case the resulting innovations are likely to be available only after the government, and with it policies, has changed. In addition, policies are most likely to change when they are relatively controversial to begin with. Thus, in designing strategies to promote research for government goods, it is important to consider the relationship of the product to potential changes in policies, and to attempt to tailor strategies to take into account, or, ideally, to directly address the commitment problems in the public sector.

This section has identified a number of different market failures that can give rise to underinvestment in research. These include the inability to appropriate results, excess risk arising from product uncertainty, market uncertainty, capital requirements, and public policy changes. Their importance varies for different types of research, thus establishing a case for varying the extent of public subsidies for research enterprises and for pursuing different strategies to promote different research activities. We turn next to an overview of promotional strategies available to a government agency.

PUBLIC STRATEGIES TO PROMOTE R&D

Strategies to promote research fall into two main categories: those designed to lower the cost of research, and those intended to increase the value of innovations. The latter are usually called "market-pull" or demand strategies, while the former attempt to increase the supply of research directly. We consider here four alternatives: on the supply side, direct funding of research and conducting research in-house; on the demand side, establishing prizes for innovations and creating market guarantees.

Direct funding of research activities

Grants and contracts to firms and individuals form the main alternative by which government promotes research. The chief advantages of the strategy are: first, it is relatively easy to institute; second, it enables state goals to be addressed with some precision; and third, it allows the government to retain control over the quantity of expenditures devoted to a project. In addition, many federal cost-sharing programs are exclusively for research grants and contracts so the state can take advantage of federal programs only if it institutes this method of encouraging R&D. The strategy has two main disadvantages for the promotion of research. Most importantly, it puts the government in the position of "picking winners": specifically, the agency needs to assess which research strategies are likely to yield the biggest payoffs. In consequence, this places a substantial informational burden on the state to evaluate proposals. In a new field such as automatic vehicle control systems, few firms have track records to support proposals and new firms may be mistakenly overlooked. Also, the strategy requires a significant level of state monitoring. Research effort can be very difficult to assess; for example, it may involve determining whether firms are assigning their best scientists to the project and whether they are devoting adequate support activities.

Direct subsidies for research can take several different forms. The federal government gives a tax credit to firms for expenditures devoted to R&D. This policy avoids both picking winners and monitoring; alternatively, it does not allow the government to single out those areas that are more prone to underinvestment. A potential modification of this policy would be to give tax credits for all firms that invest in particular technologies. Another related strategy is to subsidize loans to firms, either through a direct interest subsidy (for example, the Japanese government funds the Japan Development Bank, which gives low-interest loans to targeted industries) or through a loan guarantee program. The Federal Synthetic Fuel Corporation guaranteed loans to selected companies that built energy demonstration programs in the early 1980s; an expanded version of this policy is currently under debate.

The previous discussion gives some guidance about the appropriateness of different means of directly subsidizing R&D. Tax credits are of use only to companies that pay taxes and are thus not an option for subsidizing research by nonprofit firms. In order to generate additional results in basic science, it is probably necessary to rely on traditional grant policies. When the market failure in the provision of research is directly linked to capital availability -- specifically, large-scale development programs -- then programs that address liquidity constraints directly are appropriate.

In-house research

Another possibility is for the government agency to conduct research in house. For example, the Division of New Technology, Materials and Research provides in-house research and testing of materials and structures for Caltrans. In addition to avoiding monitoring problems associated with contracting out research, the strategy provides an important spillover benefit for the agency. Specifically, it provides the agency with a cadre of scientists who can evaluate outside proposals and inform the agency about research opportunities. More than 300 engineers, specialists, technicians, and support personnel are assigned to the Division. Research contracts with both state university systems and several private research institutions are managed by the Division to examine and develop innovative approaches to transportation.

A similar rationale is used by major firms who conduct basic research. A number of large U.S. firms have world class science laboratories. The corporate role of the laboratories is not just the pursuit of science -- although they have produced important discoveries that the labs' parent firms commercialized, including high temperature superconductors (IBM) and semiconducting material (ATT). The companies claim further that the expense of their laboratories is justified because the quality of scientific advice that they get from employees on a range of topics would not be available if they didn't provide the scientists with opportunities to conduct research as well as review and evaluate research done elsewhere.

Conducting research in-house is subject to several pitfalls. Civil service rules, and indeed, normal employment practices, make it difficult to either cut back or change employment in a short period of time. The former might be desirable in times of budget shortfalls, while the latter possibility might be desirable when research priorities change. Research contracting gives an agency a level of flexibility that is difficult to duplicate when activities are concentrated within the agency. An additional problem is that the agency's employees are likely to be proponents for the use of innovations developed within the agency, as opposed to technological alternatives developed elsewhere. Thus, it is probably more appropriate for an agency to undertake activities that overlap only minimally with technologies investigated in the private sector.

Prizes for innovation

Another alternative to funding research is to give some kind of financial award to successful innovators in particular technology areas. In order for this strategy to establish incentives to conduct research, the prize needs to be announced in advance. For example, the Department of Defense holds design competitions for weapons systems that require technological advances. Firms conduct research (a fraction of which is typically paid for by DOD) and then submit the results of the research. The "best" system wins a procurement contract, which is usually extremely lucrative.

A second form of prize that government can give to firms is through standard setting. A current example is the high definition television (HDTV) "standards competition" that the Federal Communication Commission (FCC) has undertaken. The FCC has announced that it will establish a standard for HDTV, probably within the next year, which will support the best design from among several proposals that are being submitted by competing television firms. The standard will yield considerable wealth to the firm or firms that will hold relevant patents, and is thus a form of prize for research activities.

Prizes have been shown to be very effective devices for inducing private firms to expand their research activities. For example, estimates of the incentive effect of DOD design competitions conclude that each dollar of procurement induces firms to spend at least an additional five cents on research. Selection of private consortia to construct and operate the four toll road projects authorized by AB 680 is an example of the prize strategy. Caltrans initiated the process by inviting firms to submit qualifications; 10 firms were accepted and invited to propose specific projects. Eight proposals were submitted. Although each proposal had cost private companies $1 million or more to prepare, only four were awarded franchises.

The prize strategy avoids many of the problems identified with direct research awards in that the government need not choose a research strategy, nor need it evaluate the qualifications of potential researchers. However, it too suffers from limitations. First, the strategy is most successful when a number of different firms can compete for the prize. For example, the defense results are very sensitive to the extent of competition. When procurement contracts are awarded on a noncompetitive basis (e.g., sole-sourced), they yield no measurable incentive for firms to conduct research in advance of the contract. Second, the government needs to be able to specify the particular product or application in advance. Thus, it is not a feasible strategy for the conduct of basic research. Third, the commitment to provide the prize needs to be firm. If a technology forcing regulation is modified in subsequent years, firms that invested in the desired technology would be left in the cold. Indeed, firms would probably discount the potential profits to reflect their assessment of the strength of the political commitment. For these reasons, commitments become attenuated over time in the political sector; as a result, the policy is probably most effective for innovations that require relatively little lead-time.

Market guarantees

The government can guarantee a market for categories of innovations, although not for specific firms, through several mechanisms. One is technology-forcing regulations. Such regulations, which are successful in such areas as automobile emission systems, establish a future date by which products must conform to new technological standards. Another option is government procurement; this strategy yields efforts in research when firms have reason to believe that their product will be adopted by the government. It is most effective when the government sets a policy in advance of adopting products that incorporate new technology. Both mechanisms could be used to develop Automatic Vehicle Indicators (AVI - electronic licence plates) for California.

As with prizes for innovation, the policy avoids problems with direct research funding in that government need not identify which firms are likely to be most successful in advance. The strategy is clearly only available to goods which the government regulates or purchases in significant quantities. Since the policies need to be credibly committed to in advance (a problem with the public sector) the use of this strategy is further limited to cases where the government can make a commitment to either follow through on purchases or not modify standards and regulations. We identify above two situations where commitments may be most credible: when they are relatively short-term, and when they are fairly noncontroversial. However this is unlikely to be an effective strategy for promoting basic research whose applications are both uncertain and only likely to be available far in the future. Market guarantees are an attractive alternative to encouraging research in areas that are likely to pay off soon (development work, in particular) and whose importance is agreed to by consensus.

CONCLUSION

This chapter highlights general guidelines for establishing an R&D policy. Underinvestment in R&D occurs for different reasons and these underlie our recommendations for strategies to encourage research. Because of the uncertainty in the conduct of basic research, direct grants are probably the only mechanism that can correct for underinvestment. Caltrans has two basic choices: contracting out for research or performing it in-house. As it is important to have some in-house capability, it is recommended that Caltrans identify a subset of basic research projects to undertake itself. Not only will this produce solutions, but it will also provide general expertise in transportation research so that Caltrans can evaluate work done elsewhere.

When contracting for research, Calrans should have clearly defined objectives. Proposals should be requested using a format requiring submissions that explain costs and benefits in reference to the best current practice. Not only will this assist Caltrans to select the most beneficial proposal, but also to assess the merit of competing research within a portfolio of research agendas. Incentives are also available for the private provision of R&D.

Prizes, when possible, are an effective means of encouraging both speculative and more certain development work. Development of technical standards for technologies like AVI, vehicle emissions, and fuel efficiency could have beneficial results. A form of direct funding that is appropriate for development projects is the establishment of a loan-guarantee or loan-subsidy program. Improvements in freight handling may respond to this latter incentive.

Although prizes and market guarantees are effective strategies for encouraging research, subsequent chapters will focus upon direct funding and in-house strategies. Concern over the effectiveness of these two approaches resulted in the legislative requirement that this report on research be initiated. However, the Legislature and Caltrans should always seek incentives that will engage private firms in the provision of R&D, as this may produce procedures and/or products which have commercial applications.

Among research problems, a case can be made for emphasizing projects that address problems which uniquely (or disproportionately) affect California. Our discussion, however, underscores the need to maintain a broad research portfolio that allows individual proposals to be evaluated in terms of their real costs and benefits to both transportation and the economy.

CHAPTER 3

COST-BENEFIT ANALYSIS

For a state to remain competitive in an expanding global economy, research and development must be an integral part of the commitment to economic growth. In this respect, transportation research serves a twofold role: it is a way in which agencies may look into their own future to set their strategic course, and it is a way to improve the efficiency of operating systems.

The current financial climate, however, imposes strict constraints upon the allocation of funds for research. California can no longer invest money in research without clear objectives and knowledge of probable outcomes; therefore, techniques like cost-benefit analysis (CBA) are required to examine the merits of, and guide the choice between, competing proposals. Although widely used in transportation, CBA is seldom employed correctly, and special care is required in order to avoid errors. The following requirements are essential:

- Uniformity in assessments across proposals must be preserved. Cost-benefit analysis relies upon the art of arranging uniform assessment of alternatives that may sacrifice information available for only some alternatives.
- Goals must be defined in operational terms together with the rate of return that is expected from transportation investments.
- A base case using the best available practice must be defined so that there is a datum against which future improvements can be measured rather than the "do nothing" case.

- Timing of costs and benefits must be estimated and values discounted to current dollars.
- And results should be tested for sensitivity to changes in critical assumptions, such as the rate of discount.

Cost-benefit analysis creates a ranking among competing alternatives. The criterion used is that of maximizing monetary return (benefits) for a given amount of money invested (costs). Quantifiable estimates are preferred, but qualitative estimates can be used and the ranking can be integrated with other criteria to create a system based upon different goals. For example, Gosling and Jackson (1986) describe the methodology used by the Wisconsin Department of Transportation to allocate funding among projects. The methodology consists of an equal weighting between cost-benefit analysis and the goal of political acceptance.

The purpose of CBA is to provide a consistent ranking of alternatives so as to facilitate decision making. Several forms of CBA are available differing in the way in which costs and benefits are expressed. Benefit-cost ratio, the ratio of benefits to cost, is the most popular. However, this chapter will recommend the Net Present Value method; it emphasizes the discounting of costs and benefits to current values that are frequently omitted in benefit-cost ratios.

Net present value (NPV) is the present-day value of the benefits minus the present-day value of the costs for each proposal. The discount rate must be decided in advance and applied uniformly so as to reduce future benefits to the equivalent of present costs. For example, the benefits of this research, conducted in 1992, will be captured through more effective and less costly research in future years. However, it will require an average stream of $9295 in savings each year over 15 years for the state to recover the $80,000 cost in 1992, assuming a 10 percent discount rate. Any excess will provide a positive NPV and an economic benefit for the state. Only proposals with a positive NPV should be initiated, and those with a greater NPV should receive a higher priority if there is insufficient funding for all proposals.

This chapter begins with the history of CBA, and follows with a description of the most commonly used forms of CBA illustrated by examples, diagrams, and a critique of the current use of CBA in transportation. Special attention will focus on CBA applied to the appraisal of a research agenda. Currently, the choice of a proper discount rate is the issue causing the most difficulty and controversy, and a section is devoted to this topic. This chapter also recommends that sensitivity analysis be performed to see how strongly the chosen discount rate affects the result.

COST-BENEFIT ANALYSIS AS A METHODOLOGY

The theoretical justification for cost-benefit analysis comes from the idea of Pareto improvement in welfare economics (Trumbull, 1991). The Pareto notion asserts that a change is beneficial for society if it makes some persons better off without making others any worse off. When benefits exceed costs in a cost-benefit evaluation, we assume that the outcome is beneficial to society as a whole.

The strength of CBA as a tool of project evaluation is realized when the decision making unit can organize the set of underlying assumptions and data collection in cost-benefit studies so that consistency is maintained across all studies. Consistency allows comparisons of projects within the framework.

An additional value of using CBA is that it can emulate market processes by directing limited resources into the most highly valued social purposes. For instance, a correct CBA takes into account external effects of a project, such as pollution, by imputing a dollar value for any such costs or benefits. This allows decision makers to view each project with the rest of society in mind, not only those persons who benefit directly from its implementation. Cost-benefit analysis attempts to make policy choices rationally, to increase the efficiency of state intervention by transforming impacts into economic variables.

A brief history of cost-benefit analysis

The methodological underpinnings of cost-benefit analysis originated in the 19th century with the work of the "Ecole Polytechnique" (engineering school) and its appraisal of public works projects in France. Dupuit (1844) is perhaps the best known author of such studies, but Navier (1832) conducted the first appraisals explicitly considering costs and benefits. Both expanded upon simple efficiency notions, creating a format very similar to modern cost-benefit analysis. Dupuit's work is noteworthy because he also incorporated microeconomic theory into his studies.

Button and Pearman (1983) trace the modern era of cost-benefit analysis back to the turn of the century and the River and Harbor Act of 1902. Although there was substantial pre-World War II interest in cost-benefit analysis, there were no consistent guidelines for the technique in the United States until the publication in 1957 of a Federal River Basin Committee report which suggested a procedure for cost-benefit studies.

Early uses of CBA in transportation projects included studies of the Victoria Underground (subway) and the M1 motorway in England. Button and Pearman stress that transportation planning has been one of the few fields where cost-benefit work is frequently completed prior to actual investment.

During the 1970s and 1980s, an improved appreciation for the limitations of CBA developed in addition to new ways for the planner to account for items and ideas that had been neglected or omitted from previous studies. The creation of computerized methodologies such as the Productivity Estimation Computer Model (Lewis, 1991) in the United States and COBA (Cost Benefit Analysis) in England allowed greater standardization of project evaluation and improved comparisons among competing sets of similar projects. Evaluations for projects funded by the United States Department of Transportation during this time were required to include an assessment of alternative projects, including the "no build" alternative, using CBA. The requirements prompted several attempts to modify and extend aspects of the existing theory (Rubenstein, et al., 1980) but the basic methodology remains unchanged.

Cost-benefit analysis is a well established and efficient way for an agency to evaluate the allocation of scarce resources among alternative proposals. The history of CBA illustrates not only its applicability to all types of projects, but also the need for such a decision-aiding tool.

TYPOLOGY FOR COST-BENEFIT ANALYSIS

Cost-benefit analysis comes in a number of forms which differ in the way in which either costs or benefits are expressed. Although each method has its merit, **net present value** is recommended.

Cost-effectiveness analysis

In cost-effectiveness analysis there exists a unique goal and different ways to achieve this objective. The problem is to identify alternative courses of action and to calculate their costs. Costs of alternatives are then ranked from lowest to highest. This method is used when a set of alternatives to be ranked yields the same benefits; e.g., when a tangible goal is set by a government or agency and is competed for by alternative proposals. Bids to construct an interchange would be an example. Achievement of the goal is the sole benefit, and costs are the basis for comparison. A nonpecuniary example would be the analysis of different methods to reduce highway fatalities; the benefit is stated as a goal and the cost of alternative strategies is analyzed.

Cost-effectiveness takes into account only part of the available information. By ranking alternatives in terms of cost alone, the disintegrate is assuming that one of the alternatives must be chosen. However, it is possible that none of the alternative projects achieve benefits that exceed their real cost, and the economy would be better off with no action. For example, the proposed interchange may cause more direct and indirect costs than benefits for the adjoining community and travelers. When enhanced productivity and economic growth are desired, it is essential that all costs and benefits be considered.

Benefit-cost ratio

A more complete measure of welfare is the benefit-cost ratio. This is the ratio of discounted benefits to discounted costs. The measure is constructed so that projects with higher benefits than costs will have larger benefit-cost ratios. The algebraic formula is:

$$\textbf{Benefit Cost Ratio} = \Sigma[B_t/(1+r)^t] \,/\Sigma[C_t/(1+r)^t]$$

where B is benefits, C is costs, and r is the discount rate (or the rate at which money could be invested elsewhere in the economy) and t is the number of time periods involved, usually the projected lifetime of the particular project. A project is considered beneficial to society if the ratio is greater than one.

Discounting corrects for the different value assigned to having equivalent amounts of money now or in the future; i.e., a dollar next year being worth less than a dollar now. To bring costs and benefits to a common reference point (the present) we divide by one plus the discount rate for each time period. Caltrans uses the "pooled money investment" return as their current discount rate.

In a benefit-cost ratio analysis, substantial variation in the results can occur as the result of choosing different discount rates. Therefore, this form of CBA is difficult to use in transportation projects because both the costs and the benefits involve long time periods. Furthermore, discounting procedures are a frequent cause of error.

Net present value

The preferred method for expressing the relationship between costs and benefits is net present value. This criterion is similar to the benefit-cost ratio, but it expresses the result in current dollars rather than a ratio. The formula is written as:

$$NPV = \Sigma(B_t - C_t)/(1+r)^t$$

The larger this value, the more a project improves welfare. Expression of the result in current dollars is a real advantage for decision making, and most of the information required to calculate NPV is available from the same data used to calculate cost-effectiveness and cost-benefit studies (Box 3.1). Lewis (1991) illustrates the superiority of NPV by recalculating the results from an UMTA sponsored study that appraised four transit alternatives in reference to the goal of lowering "cost per new transit rider." The results are instructive: whereas the cost effectiveness study appraisal favors the light rail option, NPV shows that no alternative yields a positive benefit over the base case that entailed using the existing infrastructure more effectively. Lewis cautions, however, that the results would change if different discount rates were used, or if a longer project life was assumed.

These cautions are appropriate; NPV, like other methods of CBA, is a technique for appraising similar proposals. It should not be used to predict the financial outcome of a proposal or project.